AN INVESTIGATION OF WATER-BORNE WASTES CONTRIBUTING TO THE POLLUTION OF THE RIO CAUCA

A THESIS

by

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Submitted on the seventh day of August, 1963, to the Department of Civil Engineering of the Graduate School of Tulane University in partial fulfillment of the requirements for the degree of Master of Science by

PREFACE

A memorandum of agreement between the Universidad del Valle, Cali, Colombia, and Tulane University, New Orleans, Louisiana, was signed in September 1961 for the purpose of establishing a continuing exchange of medical scientists between the two universities for cooperative research and training in the health sciences. The signers of the agreement were confident that the program would lead to closer international understanding and to the advancement of health sciences. This program is known as the International Center for Medical Research and Training (ICMRT) and is funded primarily by a grant awarded to Tulane University by the National Institutes of Health, U. S. Public Health Service, under the authority of the International Health Research Act of 1960 (P.L. 86-610).

The ICMRT has been organized to permit a member of the faculty or a student of either university to submit a research proposal. Approval of the proposal by the ICMRT Committee permits the research to be accomplished with the principal investigator having complete responsibility for the conduct of the project. Within this aspect of the

organization, Dr. F. W. Macdonald, Professor, Division of Environmental Hygiene, Department of Tropical Medicine and Public Health, and Professor, Civil Engineering Department, Tulane University, submitted a proposal for "A Study of the Pollution and the Natural Purification of the Cauca River and a Study of Waste Stabilization Ponds."

The proposal received approval with field studies to commence during the summer of 1963 with Dr. Macdonald as Project Director. The field investigations were planned to be accomplished by students of both universities, and it was in the capacity of such an investigator that I was asked to participate in the project. The investigation of that portion of the study regarding the sources and quantities of waste discharged into the Rio Cauca provided the basic data used in the preparation of this paper.

I would like to take this opportunity to thank Dr. Macdonald for permitting me to take part in this survey and for the counsel and advice received during the planning and implementation of this phase of the study.

I am deeply indebted to Dr. Luciano Peña, Dean of the Faculty of Sanitary Engineering, Universidad del Valle; Dr. Patrick Owens, Rockefeller Foundation; the Faculty of Chemical Engineering of the Universidad del Valle; the Empresas Municipales, Seccion Aqueducto; and the Cauca Valle Caldas for their assistance in providing the transportation,

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facilities, and at times the personnel necessary to collect and analyze the samples required to accomplish the survey. Special acknowledgement is due Professor Leonardo Santamaria, Universidad del Valle, my co-worker in the study. Without the assistance of these kind and gracious people the collection of information and data so necessary for this study would not have been possible.

Finally, and most importantly, sincere gratitude is expressed to the Civil Engineer Corps, United States Navy, and the U. S. Naval Postgraduate School, Monterey, California, without whose selection, counsel, and advice participation in graduate study would not have been possible.

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I. INTRODUCTION

The greater part of the world lives today in a rapidly advancing and changing environment. Man has the ability and in most cases the capability to shape this environment to suit his desires. He builds cities to house his growing population, establishes factories to manufacture the great variety of products necessary to satisfy and increase his growing standards of living, constructs transportation networks to move his products and people readily, and in many cases harnesses or changes nature to suit his desires. The period when man adjusted to his environment is rapidly changing to a period in which the environment is being adjusted to suit the man. The capability to shape the future and to determine the surroundings in which man and his children will live is within his grasp.

This change in the way of life is not without its problems. To meet the demands of his needs, man is exploiting the natural resources to provide the materials necessary to satisfy his growing industrial technology. Many of these resources are limited in quantity and as the sources are depleted or become uneconomical to exploit further he attempts to create synthetic substances to take their place.

I. INTRODUCTION

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In doing so he must utilize some other natural resource whose supply is also limited.

Our greatest concern, however, is the exploitation of natural resources for which there is no substitute and for which there is no way to create synthetically. There is probably no one natural resource more essential to the advancement of industry, agriculture, and society than clean water. Water is in fact life itself. It has no substitute.

Unfortunately, this essential to life is one of the natural resources that is limited in quantity. There is no more water available today to satisfy the growing population and its demanding way of life than there was centuries ago when the population of the world was relatively small and the use of water was negligible. Furthermore, water is one of the resources that man cannot create synthetically in quantity by utilizing some other resource.

With a limited supply of water available and demands continually growing it would seem that man would make every effort to insure that a comprehensive plan was established for the development and use of such an important resource. Such a plan would naturally include measures for the conservation of water and for the preservation or maintenance of the quality of the water. This has not been the case. As the population and industry of the United States grew the amount of domestic and industrial wastes increased. The

disposal of these wastes in the most convenient and economical manner by dumping them into surface waters continued. The pollutional load in many cases became excessive and the quality of the rivers and streams gradually deteriorated to an undesirable level.

At the same time the water quality was deteriorating the quantity of water required to support the continued national growth increased as cities expanded and new industries were established. The outfall of one user became nearer to the intake of another consumer and the re-use of water soon became common.

The industrial growth that created higher standards of living has contributed substantially to the pollution problem. The synthetic products made possible by an abundant source of high-energy have created the problem of discharging greater quantities of industrial wastes than ever before into the rivers and streams. Some of these wastes are of such a complex nature that the effects on future generations are unknown. The pesticides and fertilizers used in growing agricultural products are finding their way into the water supplies. The new synthetic products used in the home, coupled with a rapidly expanding population, are altering the composition and quantity of domestic sewage to an extent that existing conventional treatment may not be sufficient. Some of the treated effluents today are imposing pollutional

loads on the receiving waters that are greater than the raw sewage discharges of the past. A serious problem that threatens the health and welfare of the citizens of the United States has been created.

The problem of water pollution comes as no surprise. For hundreds of years it has been recognized that the rivers and streams could not be overloaded with wastes without creating serious problems. The problems were ignored or considered with little interest for years. Officials were hesitant to introduce legislation that restricted the use of or imposed controls on public waters. Discussion and legislation to conserve water and to maintain or improve the quality of the rivers and streams has assumed importance on a national level only in the last twenty years during the war and post-war expansion period.

This problem of water pollution is not restricted to the United States. It is common to all the heavily populated and industrialized countries of the civilized world. It is a creeping and spreading problem that will eventually affect all of the nations of the world. It has reached a stage of extreme seriousness in the United States but perhaps it will affect even more the nations that are presently in the throes of developing their industries.

The problem in the United States has gradually reached its present level through the course of two industrial

revolutions. It has taken nearly a hundred years of growth to reach this level. During this period waste treatment facilities were constructed to combat this growth. The newer industrialized countries will not have such a transition period. They are suddenly being thrown into a period of industrial development of the most advanced technology where they will accomplish in perhaps twenty years what it took other countries a hundred years to do. The problem of pollution will be thrust upon them just as quickly.

There is no doubt that such a pollution problem in these newly developing countries must be considered and steps taken to solve it. Recognizing that pollution of their streams and rivers is occurring and taking immediate action to prevent its uncontrolled growth is required. This, however, is no small chore. To accomplish it, basic data on the water quality of the rivers and streams must be established and maintained.

Basic data in pollution control consists of collecting information regarding the sources, types, and quantities of pollutants; determining the effect of the pollution on the quality of the receiving waters; determining the intended use of the water; planning of pollution prevention and control measures; and studying the economical aspects associated with the control. This data must be collected and evaluated on a continuing basis if pollution problems are to be

recognized and eliminated before they reach serious proportions. The gathering of such data is a time consuming and at times a difficult task, but it is necessary if a pollution control program is to be effective.

There is little information at the present time which gives any indication of the degree of pollution existing in the Rio Cauca in the vicinity of Cali, Colombia. It is the purpose of this study to determine the quantity and quality of the domestic and industrial wastes being discharged into the river. The results obtained will provide basic information from which the present self-purification of the river can be determined, the increased pollutional load at any future time can be calculated, and the degree and type of waste treatment required can be determined. The study will not be complete and conclusive in itself. It is considered as the primary but necessary step in the establishment of a continuing program of study for the control of pollution in the Rio Cauca.

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II. WATER POLLUTION

Importance of Water

In the urbanized sections of the civilized world it is taken for granted that each time a faucet is opened a plentiful supply of a potable and palatable water will issue forth. Little or no thought by the user is given to the question of where the supply was obtained or what treatment the water was subjected to prior to distribution. Even less thought is given to where the excess or waste water is conveyed or discharged. It is sufficient for the population to assume that an apparently endless supply of water so necessary to life is available at a reasonable cost.

The fact that water is an essential item for sustaining life cannot be overemphasized. It has been said that water is the bearer of life, for life is sustained in and by protoplasm. "Without water there can be no protoplasm. Without protoplasm there can be no life."[1]

The availability of an adequate supply of water has been a prime consideration for sustaining life since the earliest days of civilization. Man cannot exist long without

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[1]Thomson King, Water: Miracle of Nature (New York: The Macmillan Company, 1953), p. 6.

water and as a result has always settled in areas where a sufficient quantity of this necessity for life was available. When such a settlement outgrew its supply of water it was forced to move or to construct a system that would transport sufficient water to the community. This supply, in addition to the normal precipitation, was required to provide the quantity of water necessary for human consumption, a supply for domesticated animals, environment for aquatic life, and water for the growth of plant life that served as a source of food.

In addition to its use as a necessity for sustaining life, water has been used to help achieve the social and economic development of the world. In the early years of the advancement of civilization water transportation was the easiest and in many cases the only method possible to move goods and people from one area to another. The advancement of other forms of transportation networks in recent years has reduced to some extent the necessity to rely upon water as a major inland transportation system. However, the continued development and maintenance of river channels, canals, and ports are sufficient evidence that water transportation is still an important factor in economic development.

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The industrial expansion and advancing technology which led to the economic growth of recent years would have

been impossible to achieve without the use of water. Electrical energy generated in quantity by hydro-electric installations has helped make possible many of the present day high-energy manufacturing processes. These processes often require the use of tremendous quantities of water for cooling, cleaning, as a solvent, and as a transporter of wastes.

The use of water as a means of transporting wastes is not restricted to industry. As centers of population grew it became evident that the removal of wastes generated by the inhabitants was most efficently and economically performed by water. Approximately seventy per cent of the water supplied to a community is disposed of as spent water. It is only natural that the sewer system used to collect this water should also be used to collect the human wastes generated by the population. In this way, the offensive and potentially dangerous wastes of the community are rapidly and safely conveyed by water to a sewage treatment plant or to a point of discharge into a receiving stream. This conveyance by water is the only present day method to remove human waste safely from heavily populated areas when the problem of environmental health is considered.

The use of water for drinking, agriculture, industry, transportation, and waste disposal are but a few of its important uses. Its recreational and esthetic uses should

not be overlooked.

It is evident that the continued growth of population and industry is dependent to a great extent on the availability of an adequate and suitable source of water. It is mandatory that this vital natural resource be protected and utilized to the greatest degree if civilization is to survive. History has recorded the consequences when the intelligent use of water was ignored. Water supply and sewer systems existed in ancient Macedonia and in the Roman empire; extensive irrigation and canal systems were built in ancient Egypt, Babylon, and Mesopotamia. However, for various reasons these civilizations failed to secure and regulate their supply and use of water. As a consequence these systems fell into disrepair and ruin and the civilizations disappeared.

Perhaps the importance of water is best expressed by King:

> Water does not need man, but man cannot live without water. . . . For us, and for all other life, there is no substitute for water. We can truly say that all flesh is water, and with water the destiny of mankind is inextricably interwoven. So long as men inhabit the earth, their success and happiness will, in a large measure, depend on how wisely and how well they control and use water.[1]

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[1] *Ibid.*, p. 234.

Sources and Types of Pollution

As previously stated, the continued development of our social and economic way of life is dependent on the availability of water in sufficient quantities and of suitable quality. The problem of quantities of water is beyond the scope of this paper. The problem of water quality, at least as it pertains to rivers and streams, is, in part, the basis for the present study.

The use of water for nearly any purpose to which it may be subjected changes its quality to some extent. In rare instances, the use may improve the quality, but in general the normal uses of our present day civilization result in the lowering of the quality. This lowering of the quality is generally referred to as water pollution and has been defined as the introduction of substances into the water to a degree which does not create an actual hazard to public health but which does adversely and unreasonably affect such waters for further domestic, industrial, agricultural, navigational, recreational, or other beneficial use or by rendering it offensive to the senses of sight, taste or smell.

Pollution is not to be confused with contamination which is the introduction into water of potentially pathogenic organisms or toxic materials which creates an actual hazard to public health by rendering the water unfit for

human consumption or domestic use.

In order to study and evaluate a pollution problem it is necessary to have an understanding of the sources and types of pollutants discharged into the receiving waters. It is generally considered that the sources of pollutional material are conveniently grouped into the following categories: domestic sewage, industrial wastes, land drainage or natural wastes, and nonwithdrawal water or recreation and navigation use wastes.

Domestic sewage is probably the most common and most widespread source of pollution. It is generally considered as the liquid waste from a community and consists largely of water, human excrement, paper, dust, food wastes, and numerous other substances. A large portion of the waste is organic in nature and is subject to the normal biological waste treatment processes. Pathogenic organisms are always potentially present in human wastes and render sewage dangerous.

The concentration of population in urban areas is creating a serious sewage pollution problem. Construction of additional treatment plants has not kept pace with the growth of communities or in many cases has been non-existent. As a result, considerable quantities of raw or partially treated sewage is presently being dumped into the rivers and streams and thus impose a pollutional load on the receiving

waters.

In many areas the sewage contains considerable industrial waste as a result of manufacturing firms located in or near the community discharging their wastes into the sewer system. Much of this waste is organic in nature and as such imposes an additional load on the community treatment plant or on the receiving water.

One of the more serious problems generated by the disposal of industrial wastes is the discharge of inorganic wastes into the streams. These wastes are principally of mineral and chemical origin and have an effect on the receiving water quite different from organic wastes. Such inorganic wastes usually originate from metal or chemical manufacturing processes and are quite frequently toxic to or interfere with the microscopic life necessary for normal biological treatment.

Another type of industrial waste that is reaching importance as regards pollution are the new chemical wastes produced by the fast growing synthetic chemical industries. These wastes are extremely complex in their composition, often highly toxic to aquatic life, resistant to biological treatment, and often persist in streams for long periods. In many instances they are difficult to detect, difficult to treat, and next to impossible to remove from the water. Their long range toxic effects on man are not known.

Radioactive wastes and heat are additional industrial pollutants created by our advancing technology. Except for countries that have an advanced nuclear technology, radioactive wastes are usually confined to natural sources or fallout from weapons testing and are present in low concentrations. Heat, resulting from cooling processes in high-energy industrial production,is gradually affecting the capacity of streams and rivers to assimilate the organic load imposed upon them or to serve recreational or fishing purposes.

Land drainage or natural wastes is a source of pollution that has often been underestimated in its importance. Until recent years the silt load imposed upon a stream has been the result of erosion from streambanks and cultivated lands. The problem is now being aggravated by the practice of stripping large areas of their protective vegetation in the process of providing suburban areas to accommodate the growing population. Additionally, the runoff from the hard-surfaced urban areas is contributing oils, trash, soils and dusts, organic matter, and other wastes to the streams.

Irrigation is being practiced in increasing amounts to put more land under cultivation in order to provide food for the growing population. The return flow of irrigation waters often contains high concentrations of dissolved mineral content resulting from the percolation of the

irrigation water through the soil. Often this return flow is so highly polluted with these minerals that further use of the water is not possible until considerable dilution occurs.

Perhaps the most important sources of land drainage wastes are the runoff waters that contain considerable agricultural pesticides. These new synthetic pesticides are highly toxic and many have a long residual life. They are not removed by ordinary water treatment and although they are not at present toxic to humans they are approaching levels that are toxic to fish.

Nonwithdrawal use, or use for recreation and navigation, is causing increasing pollution in those areas where the receiving waters are used for such purposes. The pollution from recreation is principally bacterial as a result of pleasure craft discharging galley and toilet wastes directly into the water. In addition, oil, lead, and combustion products from outboard engines are causing odors and tastes in the water and at times have created conditions toxic to fish.

Navigation is an old use of receiving waters, and ships of today continue to discharge their sewage, bilge waters, garbage, and many other wastes into these waters. This practice is as old as the use of ships themselves and is creating a serious problem in those areas where the

water is used for domestic purposes or for the cultivation of shellfish.

Assimilative Capacity

The concentration of the pollutional material from the aforementioned sources depends primarily on two variables: (1) the quantity of diluting water available, and (2) the amount of polluting material introduced into this diluting water.

The quantity of water available for diluting purposes is a matter over which man has little control. He has built dams and diversion structures and has improved and developed watershed areas in order to store or regulate such waters but he cannot increase the quantity.

However, the amount of polluting material introduced into these waters is definitely controllable. This control can be exercised in numerous ways: exclusion of the waste from the stream, treatment or partial treatment before disposal, regulation of discharge to periods of high stream flow, recovery of usable pollutants from the waste, and others.

The matter of maintaining a proper balance between these two variables is in reality the solution to the stream pollution problem. If such a balance exists the river or stream will have the natural capacity to absorb the waste

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materials present and through the processes of self-purification and dilution will be capable of maintaining the quality of the water to a degree that it will not interfere with the normal downstream uses. This capacity is known as the water assimilative capacity of the river or stream.

The assimilative capacity of a stream is not constant and varies from time to time and place to place. One of the most important factors causing the variation in capacity is the amount of oxygen present in the waters. This oxygen is vital to the growth and reproduction of the variety of living things present in the stream which are responsible for the process known as self-purification of waters.

This self-purification or oxidation by living organism requires an adequate and continuous supply of free dissolved oxygen. This oxygen is withdrawn from the water by the agents of decomposition and is replenished intermittently by plants in photosynthesis and continuously by absorption at the surface. This transfer of oxygen from the air to the water is known as aeration or reaeration. The amount of oxygen that can be absorbed is a function of many factors including temperature, turbulence, exposed surface, and velocity of the stream.

Rivers and streams are not merely flowing masses of water. They are the home of a variety of living things such as bacteria, fungi, algae, worms, protozoa, and others.

These microscopic plants and animals use the organic material present in the stream as a source of food. In the process of utilizing this material as food it is decomposed chiefly by the bacteria, protozoa, and fungi. These micro-organisms break down the complex organic material into the parts they require for growth and multiplication and also into food for other organisms and plants. These organisms and plants in turn become food for larger forms of life and eventually the organic matter is reduced to relatively stable end products. This chemical reaction resulting from a life process is known as biochemical oxidation.

As long as sufficient oxygen is available to support the organisms in the stream decomposition occurs in a normal and satisfactory level. The problem of pollution occurs when organic material is imposed upon the stream in great quantities. When this occurs the population of organisms increases to utilize the material as food and to decompose it. In so doing they impose a greater demand on the oxygen content of the water. When this demand becomes greater than the ability of the stream to absorb oxygen from the air the aerobic organisms die off and the decomposition becomes anaerobic. During this period of anaerobic decomposition the stream is considered to be septic and is characterized by objectionable odors and an unpleasant appearance. This anaerobic condition persists until the organic load is

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reduced to the point where oxygen is again available and aerobic organisms reappear. Thus it becomes imperative that the waste load imposed on the receiving water be held below the level which causes this condition.

The volume of dilution water available in a stream is of major importance in determining the amount of waste that can be imposed upon it. If sufficient dilution water is present the organic load discharged into the stream will not reach the level where anaerobic decomposition sets in. Additionally, the inorganic and toxic wastes which are resistant to or react slowly to biochemical oxidation will be reduced to a concentration level which is neither harmful nor disagreeable to downstream users of the water.

Pollution Controls

It appears evident from the foregoing discussions that the major contributors to water pollution are the communities and industries. It is also evident that the users most affected by the deterioration of the quality are also the communities and industries. Further, the increase in pollution cannot be checked by restricting the growth of the communities or industries if a populous and prosperous society is to exist. The imposition of controls limiting the quality and quantity of waste discharged into the receiving waters or specifying the receiving water quality that must be maintained, presently appears to be the most

logical approach to the pollution problem.

The determination as to what restrictions or controls must be imposed to preserve or improve the quality of the receiving water is no small task. Considerable disagreement exists as to what constitutes an acceptable water quality. There are those who maintain that no wastes should be disposed of in the streams and that the spent water returned should be of equal or higher quality than when taken from the source. Others are of the opinion that a stream is a natural resource that has as one of its functions the requirement to carry away and assimilate the water-borne wastes of mankind.

The second approach is undoubtedly the more reasonable one, but the use of streams to dispose of wastes should not interfere with their other intended uses. The objective of pollution control should be to maintain the condition of a stream such that it will best serve the overall interests of the users of its waters.

Present day water pollution standards are generally one of two basic types: (1) stream standards, and (2) effluent standards. Each has its advantages and disadvantages.

Stream standards are used to regulate the quality of the receiving water. They are generally based on limiting and threshold concentrations of specific substances which

affect the beneficial uses to which the water may be put. The use of these standards takes into account the dilution and assimilative capacity of the stream. They are difficult to define and often impossible to administer, particularly if the reach of the stream is undergoing a period of expansion and development.

Effluent standards usually restrict the amount or strength of the waste that can be discharged into the receiving water. These standards can be easily defined and are relatively easy to enforce and administer. They do not, however, take into account the ability of the stream to assimilate wastes.

Regardless of which type of standards is employed it is imperative that reasonable concentrations for polluting substances be specified. Those substances that do not decompose readily and whose concentrations can increase to harmful levels to humans should of course be severely restricted to provide a margin of safety. Unreasonable limitations result in a tendency for water users to violate the standards because of the expense incurred in treating the waste. Furthermore, standards should be continuously reviewed and revised as more scientific knowledge about their effects on life are learned.

It should not be forgotten that the cost of the treatment of waste eventually falls upon the taxpayer or the

consumer of the goods produced by industry. Thus it is seen that the assimilative capacity of a stream becomes a very real and important economic factor. It is only logical that this natural resource should be used, but it should not be abused. Pollution control legislation should be initiated or reviewed with this in mind.

<u>Indicators of Pollution</u>

In order to investigate a river or stream and evaluate the quality of water it is necessary to have investigative methods by which the pollutional load imposed on the stream or river can be recognized and identified. A number of such methods have been adopted over the years and have been conveniently grouped in accordance with the type of determination made in evaluating the water. These groups of the indicators of pollution are physical, chemical, bacteriological, or biological in nature.

The physical evaluation of a water is probably the oldest. Ancient civilizations did not need scientific measures to inform them that waters which were colored, turbid, bad tasting, had an odor, or felt warm were not the best waters for their use. Later development provided methods by which numerical values could be used to evaluate some of these physical characteristics which were purely relative to the senses of the individual doing the testing, e.g., color, turbidity, odor and taste.

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Other physical characteristics which are of importance in stream studies include volume of flow, variation in flow, degree of turbulence, velocity, solids, floating materials, radioactivity, and when it differs significantly from water, the specific gravity of a waste.

As the water quality of a stream changes there is usually a change in the chemical characteristics if the water has been altered by the addition of a pollutant. Therefore, determinations which reflect a change in the chemical characteristics are known as chemical indicators. These chemical indicators of pollution fall into two categories: (1) concentration of a substance not previously detected, and (2) a change in concentration of a substance previously found in the water.

One of the most important of the chemical indicators is the determination of the amount of Dissolved Oxygen (DO) present in the receiving water or in the wastes. As previously stated, the presence of oxygen is essential if the forms of life so necessary to aerobic decomposition are to be supported in the waters. As a result, the determination of dissolved oxygen is a rapid method of determining the presence and source of decomposable organic pollution. It, therefore, also serves as an indicator of the recovery of a stream as illustrated by the use of the dissolved oxygen sag curve.

Another of the chemical indicators related to the dissolved oxygen measurement is the test for the Biochemical Oxygen Demand (BOD). This test is used to determine the oxygen required to decompose bacterially and under aerobic conditions the organic material in the stream, river, or waste effluent. It does not measure the oxygen required to oxidize a material that does not readily serve as a food for the microorganisms responsible for the self-purification of a water. The oxidation of material of this type is best determined by another of the chemical indicators, the Chemical Oxygen Demand (COD). The COD cannot be used as a direct measurement of oxygen relationships but it is a rapid chemical procedure that has certain advantages in industrial waste evaluation.

The measurement of the hydrogen-ion concentration, pH, is an indicator of the freshness of sewage, the presence of industrial wastes that are strongly alkaline or acid, and of the corrosiveness of water. This chemical indicator is often employed in water-quality studies to trace sources of pollution and to determine the suitability of a water for domestic or industrial purposes.

Additionally, chemical analyses are made to determine the presence and concentration of various heavy metals, minerals, synthetic organic chemicals, and others. Many of these materials are toxic or have deleterious effects on

humans and must be detected and concentrations determined if the water is to be used for domestic purposes.

Another very important indicator of pollution that has its major application in water quality studies of streams used for domestic purposes is the determination of the type and quantity of bacteria present. It is often used in stream surveys to trace sources of pollution.

The bacteria in water are derived from many sources: the air, soil, living or decaying plants or animals, mineral sources, and fecal excrement. Fortunately many of these bacteria have little sanitary significance as they die rapidly in water, have no known association with human wastes, or are commonly found in the air and soil.

However, as previously stated, pathogenic bacteria found in human wastes are always a potential hazard as long as they are present in waters used for human consumption. To detect the possible presence of these pathogenic organisms bacterial indicators have been found which are always present in human and animal wastes, always present when pathogenic bacteria are present, always persist longer than the pathogenic bacteria, and by their absence excludes the probability of the pathogenic bacteria being present. The test for coliform organisms to indicate that human or animal wastes are present in a water is generally employed.

The coliform group of bacteria is composed of coli

humans and must be detected and concentrations determined if the water is to be used for domestic purposes.

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discharged in fecal matter (Escherichia coli) and of non-fecal coli (Aerobacter aerogenes) which originate in soil, grain, and decaying vegetation. The test commonly employed for determining the presence of the coliform group does not differentiate between these two types of bacteria. A positive result in the coliform test does not always indicate that fecal contamination, and thus the possibility of pathogenic organisms, is present in the water; it could have been caused by the non-fecal coli group. Therefore, although the coliform test is not positive proof that human or animal wastes are present in a water it is an indicator of the possible presence of such wastes.

A quite different way of evaluating pollution is the observation of the presence or absence of certain biota in the streams or rivers. Inasmuch as plants and animals vary in their tolerance of oxygen levels it is possible to observe the presence of certain species of life and to estimate the oxygen level in the stretch of the stream under consideration. However, as the other indicators of pollution are easier to apply and evaluate, the biological indicators of pollution are somewhat underdeveloped and are used to a much lesser extent.

Analytical methods have been developed using the above indicators to obtain the information necessary for the detection of pollution in the rivers and streams. In

order to avoid confusion in comparing results made by different investigators, and to provide data that is acceptable in courts, certain analytical methods have been designated as standard. Those procedures described in "Standard Methods"[1] have been accepted as the general standards in the United States.

It should be remembered that criteria and methods for the detection and determination of pollutants using the present indicators are man-made tools that are often imperfect and may be replaced as additional scientific knowledge is gained. They are, however, the basic tools in a water quality survey and should be used to the greatest extent possible, keeping in mind their limitations and applying them intelligently to the problem at hand.

Water Quality Surveys

Water quality surveys may be conducted for a variety of purposes such as the determination of a suitable source of supply for domestic or industrial use, the use of a stream or river as a receiving water for wastes, the determination of the degree of treatment required for certain wastes prior to discharge, the determination of the degree of pollution present in the water, the suitability of a

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[1] Standard Methods for the Examination of Water, Sewage and Industrial Wastes (11th ed.; New York: American Public Health Association, Inc., 1960).

water for recreational use, the study of waters overlying shellfish areas, and others.

Regardless of the reason for the survey, one of the basic objectives is the determination of existing water conditions and qualities. To accomplish this objective it is necessary to plan and implement a study for the collection and analysis of numerous water samples. The greater the number of samples collected and the more extensive the physical, chemical, bacteriological, and biological determinations made, the more complete and informative the survey will be.

Unfortunately, most surveys are limited as to the amount of time and money that can be expended in the collection and evaluation of such data. In addition, nature often dictates a time period within which such data can be collected and still be of value in the specific program planned.

As a result, many water quality surveys are designed to provide only basic data necessary to evaluate a particular phase of the pollution, or suspected pollution, in a stream or river under study. This has been the case in the study of the Rio Cauca.

III. RIO CAUCA WASTE STUDY

Purpose of Study

A preliminary sight survey of the Cauca River in the vicinity of Cali, Colombia, was conducted in the summer of 1962 by Dr. F. W. Macdonald and Dr. Luciano Peña to assess conditions which were possibly contributing to the pollution of the river. This survey revealed that various cities were directly or indirectly discharging raw sewage into the Rio Cauca and that a rather large industrial complex north of Cali was believed to be discharging quantities of industrial wastes into the river.

Inquiries made to local governmental agencies revealed that no stream pollution surveys had been made on the river and little information was known regarding the wastes discharged into the river. Flow records of the Rio Cauca indicated that the dilution factor provided at minimum flow periods appeared too low to prevent pollution of the river.

As a result of this preliminary survey a pollution study of the Rio Cauca in the vicinity of Cali was proposed to be undertaken jointly by the Faculty of Sanitary Engineering, Universidad del Valle, and the Division of Environmental Hygiene, Department of Tropical Medicine and Public

Health, Tulane University. The study was to be conducted by sanitary engineering students of the two universities under the supervision and direction of faculty members of the universities.

Considerable interest in the study was expressed by Empresas Municipales de Cali, the company responsible for public utilities and services in Cali, and the Cauca Valle Caldas (CVC).[1] Both organizations offered their assistance in carrying out portions of the study which was to be initiated during the summer of 1963.

The pollution study as presently planned will continue for a number of years. The first portion of the study will be devoted to the determination of the source and quantity of wastes being discharged into the river. The information obtained during this study will be combined with data collected regarding stream conditions to determine the extent of pollution, the degree of recovery or self-purification of the river, and the amount of additional waste that can be added to or must be prevented from entering the river.

From the information provided by this stream pollution survey, plans will be formulated for the construction

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[1]CVC is the identifying symbol of the Corporatión Autónoma Regional del Cauca (Autonomous Corporation of the Cauca Region). The CVC was established by governmental decree in 1954 as a TVA type organization charged with the development and use of natural resources, power generation, and the improvement of communication and transportation systems in the upper Cauca Valley. This valley includes all or part of the three Departamentos (departments) of Cauca, Valle, and Caldas (CVC).

of stabilization ponds to treat industrial or domestic wastes in the critical areas of the river. These ponds will provide an economical method of waste treatment and will serve to demonstrate to local municipalities and industries the importance of waste treatment facilities. The ponds will further provide facilities for future studies of efficiency of operation under local conditions and for a study of mosquito breeding in stabilization ponds.

It is intended that the project will provide much needed research on the pollution of the Rio Cauca and will serve as a training area for students in sanitary engineering investigating pollution problems. As previously stated, the survey will be conducted by students of both universities and will extend over a period of years.

The first portion of the survey, and the one forming the basis for this paper, is the determination of the quality and quantity of water-borne wastes entering the Rio Cauca in that portion of the river under study. This determination is essential in establishing base line values of existing water conditions. These values must be known if future evaluations of the quality of the river are to be meaningful in the surveillance of the stream or if the effectiveness of future waste treatment facilities on the condition of the stream is to be determined.

Historical Background

The importance of the Rio Cauca, and in particular that section near Cali, in the economic growth and development of Colombia is best appreciated if one has some background of the history, physical features, and climate of the country.

The Republic of Colombia is located in the northwest corner of South America and forms the junction with Central America. It is unique among the countries of South America in that it has a coast on both the Pacific Ocean and the Caribbean Sea. Land frontiers are formed with Panama, Ecuador, Peru, Brazil, and Venezuela as shown in Figure 1. Its total land area is approximately 440,000 square miles and is equal in size to Texas and California combined. Its population is estimated to be fifteen million.

Three cordilleras or chains of the Colombian Andes originate just north of the border with Ecuador and terminate in the western and northern portions of the country. The Western Cordillera parallels the Pacific coastline and terminates in the coastal plain before reaching the Caribbean. The Central Cordillera, principal and highest of the chains, is separated from the western and eastern ranges by the Magdalena River to the east and the Cauca River to the west. The Eastern Cordillera, longest of the chains, stretches northward to the Venezuelan border near

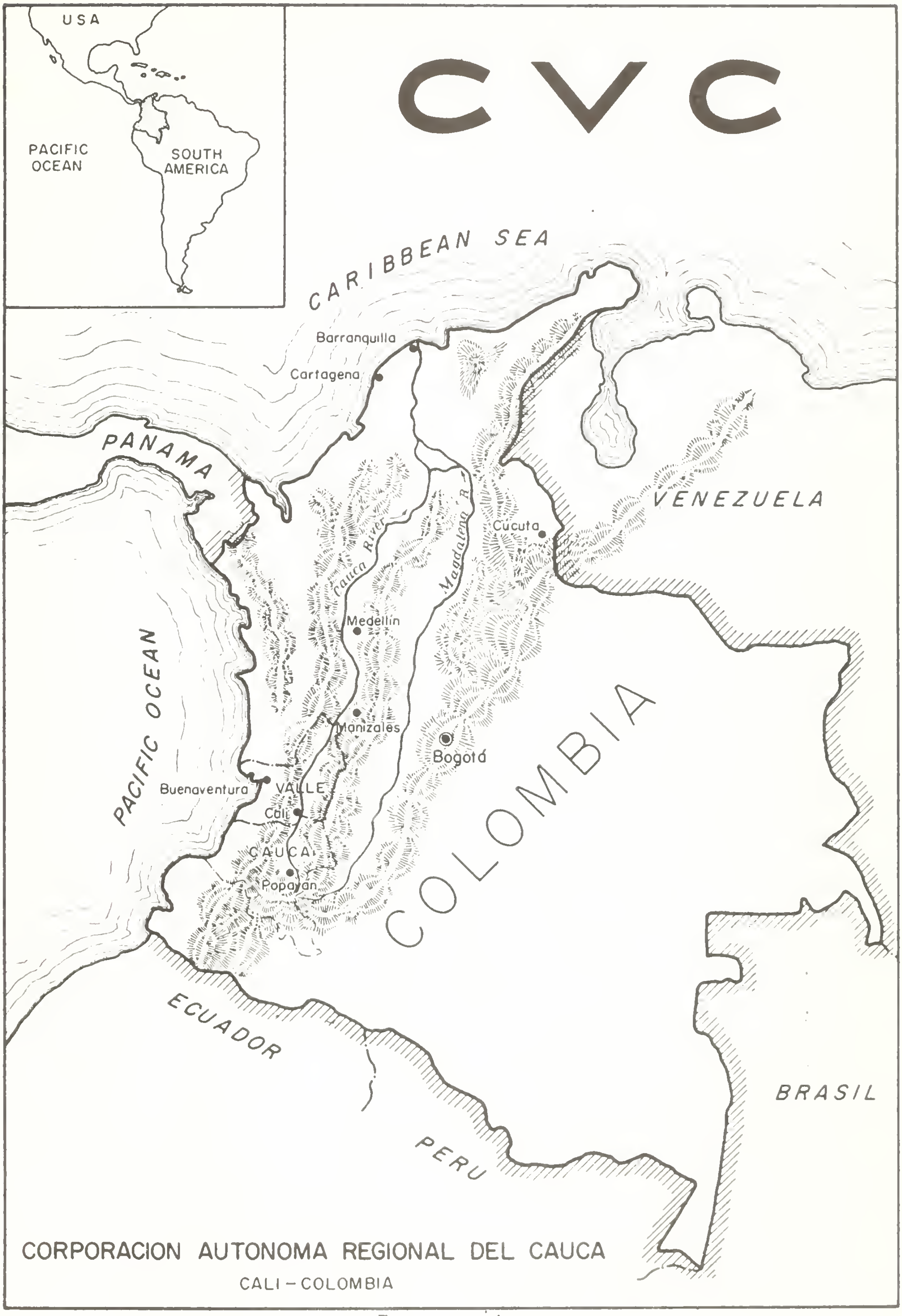

Figure 1.—Area Map

the Guajira peninsula. This range sharply divides the mountainous north and west sections of Colombia from the low lying plains and jungles bordering Brazil, Peru, and Venezuela.

Although Colombia is in the torrid zone and extends from about 4° South latitude to 12° North latitude, the climate is quite varied as a result of the great differences in elevation which range from sea level to 18,800 feet. The coastal areas and the lowlands up to an elevation of 1500 to 2000 feet are considered hot country and are characterized by extensive moisture, dense forests, and a generally unhealthy tropical climate except in the larger cities. From 2000 to 7500 feet are the sub-tropical districts of the fertile valleys and mountain slopes. These areas have a pleasant temperature and are the most productive in the country. The temperate zone covers the range of elevation from 7500 to 10,000 feet and above this elevation are the bleak and icy mountain wastes.

The most densely populated areas of the country are located in the interior in the sub-tropical and temperate zones and are quite isolated from the coastal area by the extensive mountain chains. These physical barriers between the ports and the centers of population in the interior and the separation of the interior cities from each other have resulted in the rather slow development of the country.

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Road and rail transportation are not well developed, and continuous systems of transportation to the interior are practically non-existent.

The depression between the Western and Central Cordilleras is conveniently divided into three plain areas. The southernmost of these is drained by the Rio Patía which empties into the Pacific Ocean. The central and largest of the plains is drained by the Rio Cauca which originates in the mountain area in the southern part of the Colombian Andes. The river flows north-northeast some 635 miles before uniting with the Magdalena River about 200 miles from the Caribbean Sea.

In the upper region of the central plain, before it flows through the canyons and gorges near and below Cartago, the Rio Cauca is an alluvial river which meanders over the valley floor to a considerable extent. This portion of the Cauca plain has the aspects of an old lake filled with deposited material. This section of the plain is known as the Upper Cauca Valley or more generally as the Cauca Valley and is comprised of the area indicated in Figure 2.

The terrain of the valley is quite varied and ranges from the river plain to very steep and rugged mountains flanking the plain. As a result of the variation in altitude, the valley has a wide climatic range which supports a variety of agricultural products in great abundance. The

Road and rail transportation are not well developed, and continuous systems of transportation in the [illegible] are practically non-existent.

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Figure 2.—The Cauca Valley

warm plain area is well suited for raising beans, cotton, corn, rice, sugar cane, tomatoes, cacao, and tropical fruit. The higher and cooler mountain slopes support the production of coffee, barley, corn, potatoes, wheat, and other vegetables. The growing season extends throughout the year.

Much of the plain area which is ideally suited for the production of agricultural products is devoted to pasture lands for cattle. This is a result of two related factors. First, the Rio Cauca overflows its banks nearly every year. Rather than risk the loss of a crop, the inhabitants utilize the land for grazing purposes. Second, the banks of the river are higher than the adjacent land and drainage after a flood or normal rainfall is either poor or non-existent in many areas.

Damage caused by the annual flooding is quite small. The cattle are driven to higher ground until the floodwaters recede. No damage is suffered by the towns in the valley as the early Spanish settlers located their villages on the high ground back from the river in order to be above the flood zone and to be located in a more healthful environment. This healthful environment with its associated pleasant year round climate, abundant supply of tropical fruits, and fertile ground resulted in the establishment of Spanish settlements in the valley in the 1530's.

However, the area was virtually isolated from the

rest of Colombia and the world as a result of the mountains flanking it. For centuries travel into and out of the valley was restricted to difficult journeys by horseback, and goods were transported to the inhabitants by pack mules. As a result, the valley remained virtually unchanged in its development for nearly 400 years.

An example of the difficulties encountered in developing the valley was the construction of a sugar mill in Palmira at the end of the nineteenth century.[1] The equipment for the mill was transported by pack animals from the railroad terminus near the port of Buenaventura on the Pacific coast over the Western Cordillera to Palmira, a distance of approximately eighty-five miles. The transportation and installation of the equipment took three years to accomplish and when completed the plant had a capacity of only eight tons per day.

Railroad transportation from the deepwater port of Buenaventura over the Western Cordillera and into the Cauca Valley was not initiated until 1915, and a road over which motor vehicles could traverse was non-existent until 1945.

The region is presently linked to the rest of Colombia and the outside world relatively well. These connections, completed in recent years, coupled with the

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[1] Miguel Fadul and Enrique Peñalosa, La Industria Azucerera en la Economía Colombiana (Cali, Colombia: ASOCAÑA, 1962), p. 17.

climate and environment, as previously mentioned, have resulted in a rather rapid development of the area in the past twenty years. Approximately one-fourth of the population of Colombia is located in the valley and it was logical that such an available labor force and economic market resulted in the location of numerous industrial firms in the area.

Cali, capital of the Departamento del Valle del Cauca, is a rapidly expanding city located on high ground near the Rio Cauca and extends into the foothills of the Western Cordillera. The growth of the city is an indicator of the development of the valley. Settled in 1536, it took more than 300 years to reach a population of 101,000 in 1938. This population more than doubled in the next ten years and was reported as 284,000 in 1951. The present population is estimated to be 700,000 with an annual growth rate of eight per cent.

Accompanying this population growth in the past twenty years has been a considerable industrial development in and around Cali. The area downstream between Cali and Yumbo is rapidly developing into an industrial complex. The locating of industries in this area has been undoubtedly predicated by the following conditions: available labor supply in Cali, on high ground out of the flood zone, the railroad to the deep-water port of Buenaventura passes

through the area, nearness to the thermo-electric plant at Yumbo, and proximity of the Cauca as a source of water supply and method of waste disposal.

For the past twenty years the Empresas Municipales, and later the CVC, have been active in the planning and implementing of projects to keep pace with and advance the development of the area. A second water treatment plant using the Rio Cauca as a source of supply was constructed to augment the original facility which utilizes the waters of the Rio Cali. An improvement project to modernize, extend, and increase the capacity of the existing sewer system has been designed and is presently under construction to provide for the collection of the sewage of Cali, and the water and sewer systems are being extended to serve the numerous newly developing barrios or districts of the city. Flood protection levees and drainage canals have been constructed to drain and protect the low lying areas to the east of the city. Additional flood protection, drainage and irrigation systems, and electric generating plants are in various stages of planning, design, or construction. The area is in a period of rapid development as has never before been witnessed in the Cauca Valley.

The Waste Water Survey

The portion of the Rio Cauca under study is an eighty-six kilometer stretch extending from Paso de la Bolsa,

fifty-six kilometers upstream of Cali, to Paso de la Torre, thirty kilometers downstream, as indicated on Figure 3. This section of the river was selected as it provided an opportunity to determine water quality conditions sufficiently upstream of any major source of water-borne wastes and to permit evaluation of the recovery of the river after it passed the concentration of waste sources between Cali and Yumbo.

There are two periods of low flow in the river each year and occur during the verano (summer) or dry periods. Stream flow records which have been maintained since 1945 indicate that these periods occur in Cali in February and March and again in July through September. The second period is the most critical of the two with the minimum flow recorded as fifty-six cubic meters per second or 1977 cubic feet per second. This period of low flow coincides with the summer vacation schedules for the university students and was chosen for the overall study. The initial waste survey by necessity was conducted during the period 1 June through 15 July, 1963.

An initial reconnaissance of the river area under study was made both onshore and by boat. This survey revealed that the portion of the Cauca under study meanders over the valley floor to a considerable extent. An indication of this is shown by the fact that the straight line

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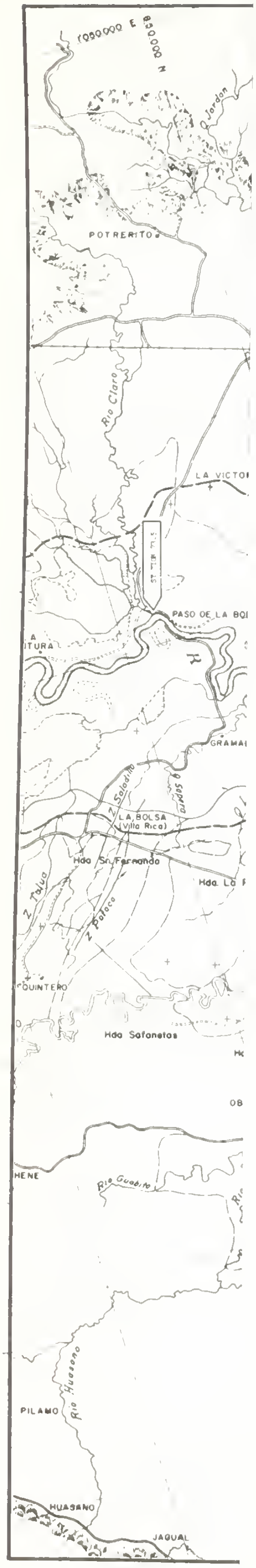
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Figure 3.--Rio Cauca Study Area

distance between Cali and Paso de la Bolsa is approximately twenty-eight kilometers whereas the river distance is fifty-six kilometers. The river banks were found to be a silty sand and indicated considerable erosion as shown in Figure 4. The land along the river is devoted mainly to agriculture and pasture land.

From this initial survey it became apparent that considerable difficulty would be experienced in obtaining samples from some of the tributary flows. In order to evaluate the conditions of pollution affecting the Rio Cauca it was deemed necessary to take samples at the points where the wastes or tributary flows entered the river. No roads, trails, or other vehicular access were in existence at some of these locations. Other sites which were accessible by road took excessive travel time to reach. It was decided that the majority of the sampling in these locations would best be accomplished by boat inasmuch as the pollution study of the river itself would of necessity have to be done in this manner. Further, the initial river study could be started concurrently with the waste survey.

It was determined that a minimum of three samples from each waste source would be required to level out variations in waste strength occurring at different hours of the day and on different days of the week. Grab samples were to be made at all locations with composite samples of

Figure 4.--Rio Cauca Bank Erosion

the sewage from Cali to be obtained if possible. These composites were desirable to show variations in daily flow and also to give an indication of the effect of industrial wastes which were being discharged into the Cali sewer system.

The samples collected were examined in a laboratory established in the Sanitary Engineering Department, Universidad del Valle. Equipment for the laboratory was provided by both the International Center for Medical Research and Training (ICMRT) and the Universidad del Valle and was adequate for the analysis and determination of certain chemical and physical pollution indicators necessary for this basic study. Samples were analyzed for temperature, pH, dissolved oxygen, biochemical oxygen demand, total solids, suspended solids, volatile solids, and turbidity. Bacteriological examinations of samples for coliform count were performed in the water laboratory of the San Antonio Water Treatment Plant, Cali, by employees of the Empresas Municipales. All analyses were performed following the procedures prescribed in Standard Methods.[1] Dissolved oxygen determinations were made using the Alsterberg (Azide) modification of the Winkler method.

Flow characteristics were determined by taking cross

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[1] Standard Methods for the Examination of Water, Sewage and Industrial Wastes.

the samples from Cell 1 to be obtained at [illegible]. These composites were desirable to show variations in waste flow and also to give an indication of the effect of [illegible] wastes which were being discharged into the [illegible] system.

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sections of the tributary flows and measuring surface velocities by timing floating objects through measured distances. Surface velocities were multiplied by a factor of 0.8 to obtain average velocities.[1] Volumes of flow were determined in this manner as records of flow of tributary streams entering the Rio Cauca were not readily available. Flow of industrial wastes were obtained from plant personnel whenever possible and estimated in other cases.

Flow measurements were made at the major sewer outfall of Cali by measuring the velocity of flow through the one meter diameter conduit under full flow conditions. The quantity so determined compared favorably with the CVC value for similar flow. Flow characteristics at periods other than full flow were determined by measuring the depth of sewage in the conduit and adjusting the values by using standard basic hydraulic elements of circular sewers.

Sampling stations have been identified by river distance in accordance with the scheme adopted by the CVC and are shown on Figure 3. In those cases where samples were taken at locations other than those identified by the CVC the station has been determined by scaling to the estimated location from the nearest known station. The

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[1]Hayse H. Black, "Procedures for Sampling and Measuring Industrial Wastes," Sewage and Industrial Wastes Journal, Vol. 24 (1952), p. 45.

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identification and description of the various sampling sites are given in the following section.

It should be noted at this time that information from several sources revealed that Cali is the only city in the area under survey, and in fact the only city on the river, that utilizes the Rio Cauca as a source of domestic water supply. This is undoubtedly due to one or several of the following reasons: Cali is the only city of considerable size in the immediate vicinity of the Rio Cauca; the other cities located back out of the flood zone find it more economical to use wells or tributary flow than to pump and treat the Rio Cauca water; and, the well or tributary flow is undoubtedly of better quality.

As a result of this situation the determination of the coliform count does not take on the importance it normally would if downstream use of the Rio Cauca included the supplying of domestic waters on a large scale. However, some of the industrial plants in the area utilize this water for domestic use when plant requirements make it necessary to treat the Rio Cauca water to obtain a high quality industrial water. Therefore, the coliform counts determined are used to verify the probable presence of sewage pollution and to identify possible sources of sewage pollution. Results are expressed as the Most Probable Number (MPN) of coliform bacteria in 100 milliliters of

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[illegible]

sample. This count is an estimate based on certain probability formulas and is an index of the coliform density in the water.

Additionally, since the water is not used for domestic purposes, and as laboratory facilities and time were limited, no attempt was made to determine or identify toxic materials, heavy metals, inorganic material, or others. Nor was the presence of pesticides or pollution from land use considered.

Nonwithdrawal use is not important as a source of pollution as the river is not used for navigation, and recreational use of the Cauca is quite limited for various economic and esthetic reasons. Most residents prefer the numerous nearby tributary streams for the limited water recreation practiced.

Survey Results

The Rio Claro, Station 73.5, is the first tributary flow entering the Rio Cauca in that portion of the river under study. The Rio Claro originates in the Western Cordillera and has no towns or villages along its course. A number of houses border its banks in the vicinity of Paso de la Bolsa and contribute some domestic sewage pollution to the river. Results of the analyses of water samples taken from this source are recorded on Table 1. The BOD load in this river is rather low as expected. Flow measurements were determined at the bridge in Paso de la

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TABLE 1

RESULTS OF ANALYSES OF SAMPLES FROM RIO CLARO, STATION 73.5

Sample No.	Date	Hour	Flow, cfs	Temp., °C	pH	DO, mg/l	5 day 20°C BOD, mg/l	Residue on Evaporation, mg/l	Suspended Matter, mg/l	Volatile Matter, mg/l	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
1	6/18	1030	350	21	6.9	6.0	0.6	--	--	--	30	--	1,134
2	6/27	1215	350	22	7.0	6.5	0.2	65	13	a	18	46,000	378
3	7/3	1220	350	22	7.1	6.2	0.1	103	4	20	18	4,300	189

[a] Gain in weight.

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[illegible] pollution is [illegible] recreational [illegible] aesthetic [illegible] numerous [illegible] recreation [illegible]

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RESULTS OF ANALYSES OF SAMPLES FROM RIO CLARO, STATION 73.5

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[a]Gain in weight.

Bolsa just prior to the Rio Claro entering the Rio Cauca.

At Station 93.4 the Rio Palo, which originates in the Central Cordillera and flows across the valley floor, joins the Rio Cauca. Various tributary rivers combine and flow into the Rio Palo in the vicinity of Puerto Tejada, a city of approximately 10,200 inhabitants, located some seven kilometers from the Rio Cauca. Multiple sewer outfalls from Puerto Tejada discharge into the Rio Palo and thus impose a domestic sewage load on the river. There are no industrial wastes of consequence discharged into the river although a sugar mill located on one of the tributary flows could be discharging its wastes into the river. The distance of flow would provide considerable purification, however, and no source of waste other than Puerto Tejada was investigated. Flow characteristics were determined at the bridge in Puerto Tejada. Results of the analyses are shown in Table 2. The high DO value indicates that no nuisance exists as a result of the organic pollution present in the river.

Jamundí, a town of 3,370 inhabitants, discharges its sewage in various locations into the Zanja del Rosario. The Zanja del Rosario flows into the Rio Jamundí and the combined flow enters the Rio Cauca at Station 103.2. Flow measurements of the Zanja del Rosario and the Rio Jamundí were made from bridges on the road between Jamundí and Cali

Bolsa just prior to the Rio Claro entering the Rio Cauca.

At Station 93.0 the Rio Pate, which originates in the Central Cordillera and flows across the valley floor, joins the Rio Cauca. Various tributary rivers [illegible] and flow into the Rio Pate in the vicinity of Puerto Tejada, a city of approximately 11,500 inhabitants, [illegible] kilometers from the Rio Cauca. Municipal [illegible] from Puerto Tejada discharge into the Rio Pate [illegible] impose a domestic sewage load [illegible] industrial wastes [illegible] consequence [illegible] although [illegible] could be [illegible] tance [illegible] however, [illegible] At [illegible] Los [illegible]

TABLE 2

RESULTS OF ANALYSES OF SAMPLES FROM RIO PALO, STATION 93.4

Sample No.	Date	Hour	Flow, cfs	Temp., °C	pH	DO, mg/l	5 day 20°C BOD, mg/l	Residue on Evaporation, mg/l	Suspended Matter, mg/l	Volatile Matter, mg/l	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
1	6/25	1210	756	20	7.6	6.5	0.7	516	111	68	35	46,000	2,857
2	6/27	1310	756	22	7.4	6.5	1.6	175	47	[a]	25	24,000	6,531
3	7/3	1130	756	20	7.5	6.0	0.7	453	271	62	40	15,000	2,857

[a] Gain in weight.

and were combined to determine the flow entering the Rio Cauca. Considerable decomposition in the Zanja del Rosario and dilution by the Rio Jamundí results in the low BOD loading from this source as recorded in Table 3.

At Station 113.0 the Zanja Granadillo enters the Rio Cauca. Water from various sources flow into the Granadillo but the entire area is devoted to agriculture and no major population centers exist. The high MPN value obtained, as shown in Table 4, is probably the result of recent pollution from one of the houses located along the banks just prior to its discharge into the Cauca. The organic pollution from this source is negligible.

In order to protect the low lying areas to the south and east of Cali from the annual flooding, the CVC has constructed a levee system along the west bank of the Rio Cauca as illustrated in Figure 5. This levee also extends west from the Cauca to the high ground out of the flood zone on the southern edge of Cali. An interceptor canal to carry away the flow of the Rio Lili, Rio Meléndez, and Rio Cañaveralejo, which previously flowed through this area, was built outside the levee. This interceptor canal was intended to carry the flow of the rivers only. However, a portion of the city presently discharges its sewage into the canal.

The canal enters the Cauca at Paso de Navarro,

and were combined to determine the flow entering the Rio Cauca. Considerable decomposition in the Zanjon del Rosario and dilution by the Rio Jamundi results in the low BOD loading from this source as recorded in Table [illegible].

At Station 11, [illegible] Cauca. Water from [illegible] but the entire [illegible] population [illegible]. The [illegible] shown in Table [illegible] from one of [illegible] to its [illegible] from [illegible]

TABLE 3

RESULTS OF ANALYSES OF SAMPLES FROM RIO JAMUNDÍ, STATION 103.2

Sample No.	Date	Hour	Flow, cfs	Temp., °C	pH	DO, mg/1	5 day 20°C BOD, mg/1	Residue on Evaporation, mg/1	Suspended Matter, mg/1	Volatile Matter, mg/1	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
1	6/20	1530	404	23	7.7	8.8	2.2	--	--	--	--	--	4,798
2	6/25	1120	404	22	7.0	6.8	0.3	107	48	37	20	7,500	654
3	6/27	1415	404	23	7.0	6.7	0.9	60	17	a	14	110,000	1,962
4	7/3	1055	404	22	7.6	6.4	0.4	113	6	9	15	23,000	872

[a]Gain in weight.

TABLE 4

RESULTS OF ANALYSES OF SAMPLES FROM ZANJA GRANADILLO, STATION 113.0

Sample No.	Date	Hour	Flow, cfs	Temp., °C	pH	DO, mg/l	5 day 20°C BOD, mg/l	Residue on Evaporation, mg/l	Suspended Matter, mg/l	Volatile Matter, mg/l	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
1	6/25	1310	10	23	7.6	5.8	0.4	337	182	61	50	--	22
2	6/27	1440	10	23	7.6	5.6	1.0	668	166	50	53	110,000	54
3	7/3	1025	10	22	>7.6	5.5	0.1	1,573	1,362	162	475	23,000	5

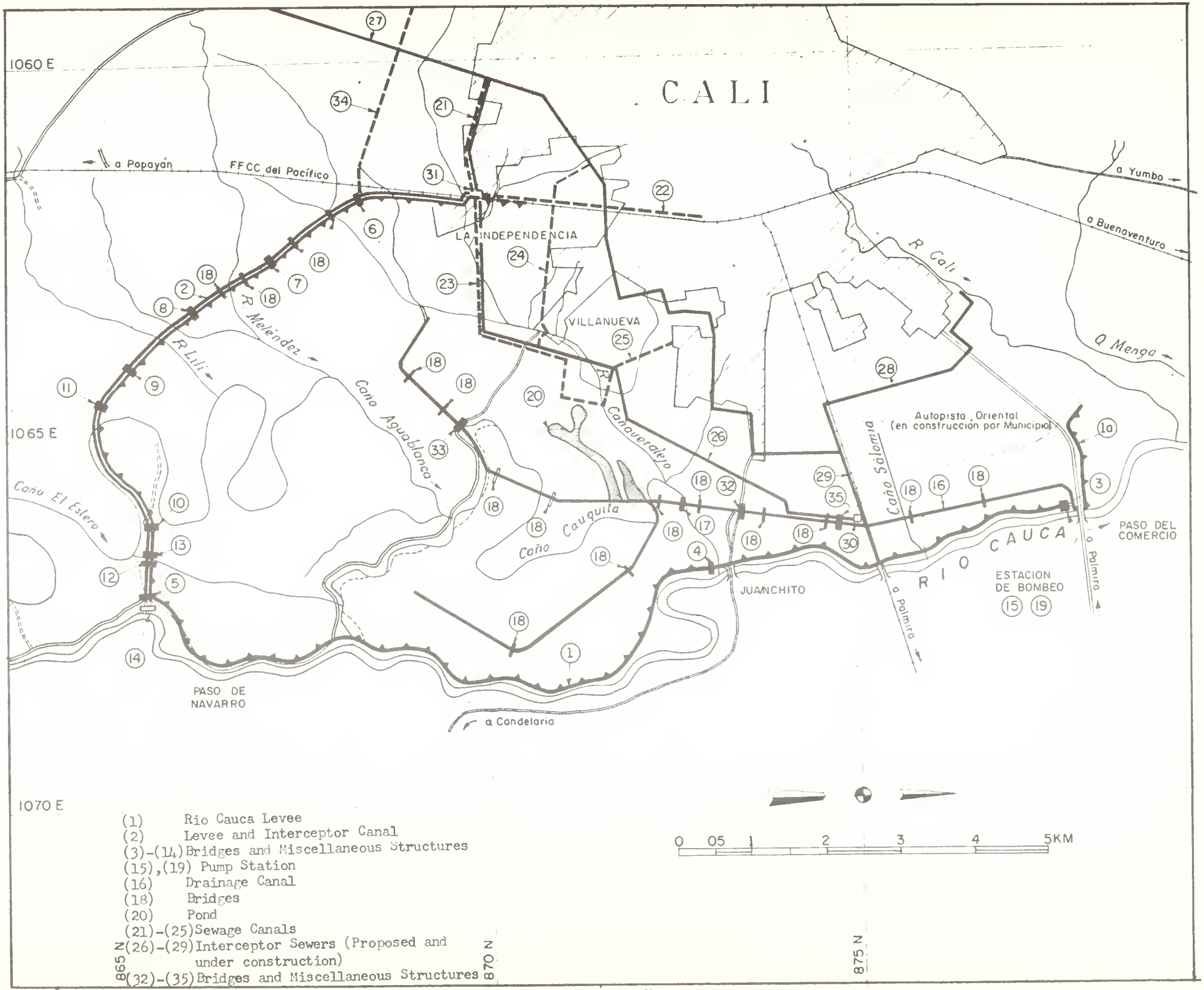

Figure 5.—Cali and Vicinity

Station 120.9, approximately nine kilometers from the source of the domestic waste discharges. The time of flow from the waste source to the point of sampling at the bridge near the Rio Cauca is estimated to be six hours and considable sedimentation and decomposition of the wastes takes place in the canal. As a result, the flow enters the Rio Cauca with a dissolved oxygen value of between zero and one milligram per liter.

A program of composite sampling at Paso de Navarro was established to determine variations in pollution loads for different periods of the day and different days of the week. A grab sample was taken each hour and composited into a single sample for each four hour period. Samples were kept on ice and analyzed the following day. This program was repeated for three days of the week; Sunday, Tuesday, and Friday. The 24 hour sampling was accomplished by employees of the Empresas Municipales.

The pattern of the strength of the waste was as expected with the higher BOD loading occurring around noon and the low occurring in the early morning, but results, as shown in Table 5, were somewhat inconsistent as a result of rains occurring during the sampling period. For example, the BOD values increased considerably during the first four hours of the rain. This undoubtedly was a result of land drainage wastes being carried into the canal and from

Station 12.9, approximately nine kilometers from the source of the domestic waste discharges. The time of flow from the waste source to the point of samples at the bridge near the Rio Cauca is estimated to be six hours and considerable sedimentation and [illegible] takes place. In the [illegible] Cauca, with [illegible] one milliforms per liter.

A [illegible] was established [illegible] for [illegible] were [illegible] [illegible]

TABLE 5

RESULTS OF ANALYSES OF SAMPLES FROM NAVARRO, STATION 120.9

Sample No.	Date	Hour	Flow, cfs	Temp., °C	pH	DO, mg/l	5 day 20°C BOD, mg/1	Residue on Evaporation, mg/1	Suspended Matter, mg/1	Volatile Matter, mg/1	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
1	6/7	0600	98	--	--	--	2.4	240	113	50	--	--	217
2	6/7	1000	98	--	--	--	4.8	250	111	40	--	--	422
3	6/7	1400	98	--	--	--	28.	320	153	80	--	--	2,466
4	6/7	1800	98	--	--	--	22.	290	139	70	--	--	1,937
5	6/7	2200	98	--	--	--	17.	230	99	70	--	--	1,497
6	6/8	0200	98	--	--	--	9.	170	--	50	--	--	793
7	6/9	0600	98	--	--	--	4.0	199	17	77	--	--	352
8	6/9	1000	98	--	--	--	4.2	246	51	67	--	--	370
9	6/9	1400	98	--	--	--	16.	419	177	135	--	--	1,408
10	6/9	1800	98	--	--	--	12.	296	110	105	--	--	1,056
11	6/9	2200	120[a]	--	--	--	52.	4,595	2,532	677	--	--	5,616
12	6/10	0200	171	--	--	--	9.	5,520	4,335	699	--	--	1,386

(Continued)

TABLE 5 (Continued)

Sample No.	Date	Hour	Flow, cfs	Temp., °C	pH	DO, mg/1	5 day 20°C BOD, mg/1	Residue on Evaporation, mg/1	Suspended Matter, mg/1	Volatile Matter, mg/1	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
13	6/12	0600	125	--	--	--	4.5	284	149	57	--	--	510
14	6/12	1000	118	--	--	--	5.0	194	49	49	--	--	530
15	6/12	1400	118	--	--	--	14.	274	102	83	--	--	1,490
16	6/12	1800	121[a]	--	--	--	16.	7,140	6,144	912	--	--	1,744
17	6/12	2200	183	--	--	--	6.	3,340	3,313	462	--	--	990
18	6/13	0200	174	--	--	--	2.8	1,239	1,091	159	--	--	440
19	6/4	1600	98	24	6.7	.5	18.	--	210	--	--	--	9,690
20	6/25	1015	98	22	6.7	.4	[b]	--	--	--	--	--	--
21	6/27	1505	98	25	6.8	.0	57.	492	57	76	134	460,000	30,650
22	7/3	1000	98	21	6.9	2.1	8.	168	66	--	30	430,000	4,310

[a] Began raining. [b] Available oxygen consumed.

Note: Composite samples collected on Friday 6/7, Sunday 6/9, and Tuesday 6/12. No temperature, pH, DO, or Coliform count were determined for these samples.

scouring of bottom deposits in the canal. No noticeable increase in BOD occurs on weekdays as compared to Sunday. This indicates that little or no industrial wastes from weekday operations are discharged into the canal.

The majority of the wastes of Cali enter the Rio Cauca through a one meter diameter conduit passing through the levee at Station 129.9. The mixture of domestic and industrial wastes that reach this outlet through a series of sewers, open ditches, and canals is septic at the time of discharge. The waste is black, malodorous, and has gas bubbles rising to the surface. Quite frequently a mass of sludge boils to the surface and floats to the river. Considerable floating matter such as garbage wastes, cans, bottles, and other debris can be seen in the open ditch prior to discharging through the conduit.

A composite sampling program identical to that used at Paso de Navarro was used at this location which is known as Cauquita. Again it was desired to know the variation in sewage strength and flow for different time periods in the week. In this case, it was also anticipated that the variation due to industrial wastes discharged into the system would be noticeable. This proved to be the case and it can be noticed from Table 6 that the BOD for weekdays is more than twice the value determined for Sunday. Variations in flow were less than expected. It is believed

TABLE 6

RESULTS OF ANALYSES OF SAMPLES FROM CAUQUITA, STATION 129.9

Sample No.	Date	Hour	Flow, cfs	Temp., °C	pH	DO, mg/1	5 day 20°C BOD, mg/1	Residue on Evaporation, mg/1	Suspended Matter, mg/1	Volatile Matter, mg/1	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
1	6/23	0600	24	--	--	--	155	1,059	794	265	--	--	3,350
2	6/23	1000	27	--	--	--	95	574	302	123	--	--	2,310
3	6/23	1400	27	--	--	--	105	475	206	111	--	--	2,550
4	6/23	1800	27	--	--	--	95	460	210	102	--	--	2,310
5	6/23	2200	27	--	--	--	70	450	240	96	--	--	1,700
6	6/24	0200	24	--	--	--	110	588	302	177	--	--	2,380
7	6/25	0600	19	--	--	--	120	1,020	--	375	--	--	2,050
8	6/25	1000	27	--	--	--	290	976	--	368	--	--	7,050
9	6/25	1400	27	--	--	--	230	1,165	654	423	--	--	5,590
10	6/25	1800	27	--	--	--	225	1,254	712	450	--	--	5,475
11	6/25	2200	27	--	--	--	300	1,410	738	531	--	--	7,300
12	6/26	0200	24	--	--	--	310	1,248	660	503	--	--	6,700
13	6/28	0600	19	--	--	--	115	780	520	249	--	--	1,965

(Continued)

TABLE 6 (Continued)

Sample No.	Date	Hour	Flow, cfs	Temp., °C	pH	DO, mg/1	5 day 20°C BOD, mg/1	Residue on Evaporation, mg/1	Suspended Matter, mg/1	Volatile Matter, mg/1	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
14	6/28	1000	27	--	--	--	205	1,190	832	366	--	--	4,990
15	6/28	1400	27	--	--	--	205	982	599	314	--	--	4,990
16	6/28	1800	27	--	--	--	165	886	451	296	--	--	4,510
17	6/28	2200	27	--	--	--	270	1,066	703	313	--	--	6,570
18	6/29	0200	19	--	--	--	155	796	441	257	--	--	2,650

Note: Composite samples collected on Sunday 6/23, Tuesday 6/25, and Friday 6/28. Grab samples showed DO 0, Temperature 28°C, and pH 6.9.

that this is the result of poor hydraulics in the collection system which permits ponding and storage in the ditches and canals during periods of high waste discharge with subsequent higher flow during periods of low waste discharge. No attempt was made to determine the specific sources of industrial discharges although inquiries revealed that a slaughter house, tannery, food canning plant, brewery, and others emptied their wastes into the municipal sewer system.

The third and final point of discharge of the wastes of Cali is via the Rio Cali. This river originates in the Western Cordillera and flows through the northern section of Cali. Water is taken from the river as it reaches the outskirts of Cali to provide a part of the domestic water supply as previously mentioned. Downstream from this intake are numerous points of discharge of both domestic and industrial wastes.

As the river flows through the residential and downtown sections of Cali it is well aerated by the substantial turbulence resulting from its high velocity and continual dashing against the numerous rocks in the stream bed. There appears to be no nuisance in this stretch of the river. However, as the river reaches the industrial and agricultural sections bordering northeastern Cali the slope of the river decreases and the turbulence is considerably reduced as the river flows across the valley floor to merge with the

Rio Cauca at Station 136.5. As a result of this less turbulent flow and additional waste load from industries in the area the dissolved oxygen level decreases to nearly zero at the mouth of the river.

Two sampling stations were established on the Rio Cali. The first was at the _barrio_ Calima bridge and was used to evaluate the waste load from Cali. All domestic and industrial wastes from Cali discharged into the Rio Cali had entered the river upstream of this point. A composite sampling program was carried out similar to the Cauquita and Paso de Navarro schemes. The variation in flow and strength are indicated in Table 7. The variation in flow is a result of rains occurring during the sampling period. The relatively small quantity of wastewater discharged into the Rio Cali has a negligible effect on the normal flow of the river. Results of the sampling indicate that the industrial wastes discharged to the river nearly triple the BOD load. No survey was made of these firms to determine quantities of waste or operating schedules of individual industries.

A small industrial development known as ACOPI exists on the Cali-Yumbo road just outside the municipal boundary to the north of Cali. A visit to the approximately fifteen concerns located in ACOPI revealed that the area is devoted to light industry and includes a textile firm, chemical

Rio Cauca at Station No. 5. As a result of this less turbulent flow and additional waste load from industries in the area the dissolved oxygen level decreases to nearly zero at the mouth of the river.

Two sampling stations were established on the [illegible]. The first was at the batata [illegible] and was used to evaluate the waste load from Cali [illegible] and the industrial wastes from Cali discharged into the Rio Cali as it entered the river [illegible]. A [illegible] sampling program was carried out [illegible] Paso de Navarro [illegible] are indicated in Table [illegible] results [illegible] relatively small [illegible] the Rio Cali [illegible]

TABLE 7

RESULTS OF ANALYSES OF SAMPLES FROM RIO CALI, CALIMA BRIDGE

Sample No.	Date	Hour	Flow, cfs	Temp., °C	pH	DO, mg/1	5 day 20°C BOD, mg/1	Residue on Evaporation, mg/1	Suspended Matter, mg/1	Volatile Matter, mg/1	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
1	6/16	0600	270	--	--	--	1.5	122	58	5	--	--	364
2	6/16	1000	300	--	--	--	7.4	143	66	7	--	--	2,000
3	6/16	1400	300	--	--	--	4.8	111	43	5	--	--	1,298
4	6/16	1800	300	--	--	--	3.5	115	20	5	--	--	945
5	6/16	2200	470[a]	--	--	--	2.6	215	150	-	--	--	1,100
6	6/17	0200	470	--	--	--	1.3	178	117	7	--	--	550
7	6/18	0600	428	--	--	--	2.9	236	97	62	--	--	1,115
8	6/18	1000	470	--	--	--	17.	266	100	90	--	--	7,190
9	6/18	1400	428	--	--	--	14.	226	90	69	--	--	5,390
10	6/18	1800	404	--	--	--	11.	211	114	59	--	--	4,000
11	6/18	2200	450	--	--	--	11.	206	85	55	--	--	4,450
12	6/19	0200	380	--	--	--	9.	220	106	66	--	--	3,080
13	6/21	0600	335	--	--	--	7.	163	90	52	50	--	2,105

(Continued)

TABLE 7 (Continued)

Sample No.	Date	Hour	Flow, cfs	Temp., °C	pH	DO, mg/1	5 day 20°C BOD, mg/1	Residue on Evaporation, mg/1	Suspended Matter, mg/1	Volatile Matter, mg/1	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
14	6/21	1000	360	--	--	--	10.	232	87	65	100	--	3,600
15	6/21	1400	380	--	--	--	9.2	250	118	75	140	--	3,150
16	6/21	1800	360	--	--	--	6.4	208	70	59	65	--	2,075
17	6/21	2200	335	--	--	--	3.2	311	137	74	130	--	965
18	6/22	0200	300	--	--	--	2.6	188	89	42	90	--	703

[a]Began raining.

Note: Samples taken on Sunday 6/16, Tuesday 6/18, and Friday 6/21.

laboratory, steel producing company making small structural shapes from scrap metal melted in an electric furnace, metal window frame manufacturing, two concerns devoted to applying insulation to electrical conductors, an ink and dye manufacturing company, construction firms, and various other small concerns. All of these firms obtain their water supply from wells and, with the exception of the ink manufacturing company, discharge their wastes to a sewer system that eventually becomes a canal prior to discharging into the Rio Cali. The total flow for this area is estimated at three cubic feet per second as measured at its entrance into the Rio Cali and consists primarily of water used for equipment cooling purposes, sanitary use, and wastes from metal cleaning processes which are acid in nature and are discharged at irregular intervals. The concerns in the area vary in their working schedules but the larger users of water are on a twenty-four hours per day, seven days per week schedule. The total number of employees in the development is approximately 700.

The wastes from this source are accounted for in the results of the samples collected at the mouth of the Rio Cali, Station 136.5, which was selected as the second sampling station on the Rio Cali. The difference between the results of this sampling as indicated in Table 8, and those found upstream, as shown in Table 7, is due in part

TABLE 8

RESULTS OF ANALYSES OF SAMPLES FROM RIO CALI, STATION 136.5

Sample No.	Date	Hour	Flow, cfs	Temp., °C	pH	DO, mg/l	5 day 20°C BOD, mg/l	Residue on Evaporation, mg/l	Suspended Matter, mg/l	Volatile Matter, mg/l	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
1	6/26	1720	305	24	6.9	0.0	25	297	120	107	50	--	41,200
2	6/28	1130	305	22	7.2	0.5	44	a	5,450	a	a	--	72,440
3	7/1	1440	305	25	<6.0	3.1	18	785	151	258	--	--	29,610
4	7/4	0950	305	21	<6.0	5.1	b	549	--	132	230	--	b
5	7/5	1300	305	26	>7.6	0.6	25	195	89	40	60	--	41,200
6	7/8	1215	305	24	>7.6	1.2	53	583	171	317	75	--	87,290

[a]River was very muddy from upstream agitation. Analysis not performed.

[b]Titration error voided results.

to the load imposed on the Rio Cali by the ACOPI development. However, the doubling of the residue on evaporation and the tripling of the BOD load results in considerably more pollution than would be expected from the industries located in ACOPI.

An investigation of tributary flow into the Rio Cali between the Calima Bridge and the mouth of the river revealed that in addition to the canal from ACOPI there were four other sources of flow entering the river. It is the opinion of this investigator that a wool scouring plant and a dry battery manufacturing company located north of ACOPI also discharge into the Rio Cali by means of two of these tributary flows. Employees of these concerns, however, insist that their wastes are discharged directly to the Rio Cauca. The outlets from these concerns could not be readily located by boat from the Rio Cauca and attempts to trace their course on foot were hampered by the low lying swampy areas between the plants and the river. Further attempts to locate the outlets are planned for the near future. The wastes from the battery manufacturing company would impose a negligible load on the river as only a small portion of its discharge is from plant use and the sanitary wastes are discharged into a septic tank prior to entering the drainage ditch. The wool scouring plant would, however, contribute a considerable BOD and total residue load to the river. As

in the lead isotopes in the aerosols by the ACOPI company. However, the doubling of the emissions on electrolysis and the trebling of the ARO lead results is considerably more pollution than would be expected from the incinerators located in Arvey.

An investigation of [illegible] between the ceiling [illegible] that in addition [illegible] other sources [illegible] of this investigation [illegible] ability considerations [illegible] discussed [illegible] [illegible] [illegible] [illegible]

previously stated, further attempts to locate the discharge from these sources are being made. The important consideration in this phase of the study is that the pollutional load entering the Rio Cauca has been determined even though the exact source has not been positively identified.

At Station 137.5 a coal washing plant has a pump station which takes from 1,000 to 35,000 gallons of water per day from the Rio Cauca for its operation. After being used, the water, which is then somewhat acid, is discharged into a low area between the plant and the river. No wastes from this plant reach the river directly.

A bulk paper manufacturing plant which utilizes imported Kraft pulp and local bagasse in its operation has an intake and discharge at Station 140.7. This plant removes six million gallons of water per day from the river for production use and with minor losses returns the same amount to the river through a submerged outlet. The wastes discharged consist of black liquor from its soda process, sanitary wastes, fiber, filler clay, and sediment from its water treatment plant. The submerged discharge prevents foam forming on the river as illustrated in Figure 6. The wastes discharged are high in solids and the pH is high as shown in Table 9. The plant operates continuously and thus contributes a considerable organic and solids load to the river.

previously stated, further attempts to [illegible] from these sources are being made. [illegible] tion in this phase of the study [illegible] ing entering the [illegible] river [illegible] The exact source has not been [illegible]

At Station [illegible] station which takes [illegible] per day from the [illegible] used, the water, [illegible] into a [illegible] from this plant [illegible]

A [illegible] paper [illegible] the Kraft p[illegible] intake and d[illegible] six million gallons [illegible] production [illegible] normal [illegible] discharged [illegible]

Figure 6.--Industrial Waste Discharged Underwater

TABLE 9

RESULTS OF ANALYSES OF SAMPLES FROM PROPAL, STATION 140.7

Sample No.	Date	Hour	Flow, cfs	Temp., ^{o}C	pH	DO, mg/1	5 day $20^{o}C$ BOD, mg/1	Residue on Evaporation, mg/1	Suspended Matter, mg/1	Volatile Matter, mg/1	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
1[a]	7/3	1200	9.3	32	9.5	--	1,100	3,696	1,124	2,290	--	--	55,222
2	7/5	1100	9.3	32	9.8	--	1,060	3,074	1,542	2,169	--	--	53,233

[a]One per cent settleable solids by volume.

The Anchicaya thermo-electric plant uses between five and nine million gallons of water per day for cooling purposes. This water is taken from the Rio Cauca at Station 146.5 and discharged back to the river at the same location. Plant records indicate that the water discharged is approximately 3°C higher than when taken from the river. The sanitary sewage from the 205 employees of the plant is also discharged with this water. No sampling was conducted as the dilution provided would reduce the BOD load to practically nothing. The greatest pollution from this plant is the addition of approximately 110 tons of fly ash daily which are discharged with the cooling water.

A tire and tube manufacturing plant was visited and found to be discharging approximately 200,000 gallons of well water to the river daily at Station 146.6. This water is used for cooling in the tube making process and for domestic and boiler use. The plant operates continuously and employs approximately 400 people. The organic load imposed upon the river is negligible considering the load imposed by the neighboring concerns and no sampling was conducted. The waste water is conveyed to the river in an open ditch and has a temperature of 32°C.

A cement manufacturing plant and a cement and cement-asbestos products manufacturing plant are located adjacent to one another at Puerto Isaacs, Station 148.2. The sanitary

wastes from the 500 employees of these two plants enters the Cauca from a single outlet. The only other continuous waste discharge is the cooling water utilized by the cement manufacturing plant. This plant utilizes approximately 600,000 gallons of river water per day for this purpose and returns the water to the river with a temperature rise of about 5°C. A slight rise in organic pollution in this water, as noted on Table 10, is believed to be caused by the waste discharges of dwellings near the plant. Occasional overflows of the slurry tank at the cement plant and periodic washing of the slurry cones in the cement products plant will add a solids load to the river but will not increase the organic loading. As a result of the very low BOD imposed on the Rio Cauca from these sources, only one grab sample was taken.

Another pulp and paper mill is located at Station 148.5. This mill also uses the soda process in its operation but makes the pulp from imported Kraft pulp and wood chips rather than from bagasse. The plant operates continuously but the discharge from the pulp cookers is intermittent. Seven million gallons of water daily from the river is used in the operation of the mill and the greater part of this is returned to the river carrying black liquor, fiber, sanitary wastes, fly ash, and sediment from a water treatment plant. The discharge is above the

wastes from the 300 employees [illegible] the sanitary sewer the CSCCS from a single system. The only other continuous water discharge is the cooling water [illegible] manufacturing plant. This plant [illegible] 600,000 gallons of [illegible] returns the water to the [illegible] about 5°C. [illegible] as noted [illegible] discharges of [illegible] Figure [illegible] months [illegible] will [illegible] the [illegible] impact [illegible] results [illegible]

TABLE 10

RESULTS OF ANALYSES OF SAMPLE FROM CEMENTOS, STATION 148.1

Sample No.	Date	Hour	Flow, cfs	Temp., °C	pH	DO, mg/1	5 day 20°C BOD, mg/1	Residue on Evaporation, mg/1	Suspended Matter, mg/1	Volatile Matter, mg/1	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
1	7/2	1100	7	27	7.7	--	5.6	199	91	11	--	--	136[a]

[a]Approximately 2 mg/1 5 day BOD is present in water when taken from river. This has been deducted from the BOD of the Cementos waste discharge prior to computing this value.

surface of the stream and considerable foaming occurs as illustrated in Figure 7. This foam persists for several kilometers downstream. The wastes discharged are high in organic material and solids and have a high pH value as recorded in Table 12.

Immediately downstream from this paper mill is a plant engaged in the manufacture of acetate yarn produced from imported acetone and acetate. The plant operates continuously and employs some 450 people. Approximately 500,000 gallons of water per day are obtained from wells and are utilized for cooling and domestic purposes. This water is discharged to the river at an elevated temperature and slightly high pH as indicated in Table 13. Plant personnel indicated that approximately eighteen tons of fly ash daily are disposed of in this water. The organic loading is quite low.

The sanitary wastes and some industrial wastes from the city of Yumbo, population 5,510, enter the Rio Cauca at Station 153.5 by the way of the Rio Yumbo. The flow in this river was estimated to be ten cubic feet per second. Results of the analyses of wastes from this source are shown in Table 14.

The final tributary flow in the portion of the river under study is the Rio Guachal which enters the Rio Cauca at Station 155.0. This river is fed by numerous

water of the stream and [illegible]
illustrated in Figure 1. This loss persists [illegible]
kilometers downstream. The wastes discharged [illegible]
organic materials and solids and [illegible]
recorded in Table 12.

Immediately downstream from this [illegible]
plant engaged in the manufacture of [illegible]
from imported acetone and [illegible]
continuously and employs some 150 [illegible]
500,000 gallons of water per day [illegible]
and are utilized for cooling and [illegible]
water is discharged to the [illegible]
ture and slightly [illegible]
personnel indicated [illegible]
fly ash daily are [illegible]
loading is [illegible]

Figure 7.--Industrial Waste Discharged to Surface of Receiving Water

TABLE 11

RESULTS OF ANALYSES OF SAMPLE FROM ETERNIT, STATION 148.2

Sample No.	Date	Hour	Flow, cfs	Temp., °C	pH	DO, mg/1	5 day 20°C BOD, mg/1	Residue on Evaporation, mg/1	Suspended Matter, mg/1	Volatile Matter, mg/1	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
1	7/2	1030	0.1	24	7.0	--	50	494	75	139	--	--	27

Note: This waste is combined sanitary waste of Cementos and Eternit.

TABLE 12

RESULTS OF ANALYSES OF SAMPLES FROM CARTON COLOMBIA, STATION 148.3

Sample No.	Date	Hour	Flow, cfs	Temp., °C	pH	DO, mg/1	5 day 20°C BOD, mg/1	Residue on Evaporation, mg/1	Suspended Matter, mg/1	Volatile Matter, mg/1	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
1[a]	7/1	1150	10.5	35	9.8	--	305	3,793	2,036	1,636	--	--	17,300
2[b]	7/5	1100	10.3	35	9.0	--	610	1,549	449	806	--	--	33,900
3[c]	7/5	1100	[c]	37	11.4	--	3,300	9,808	1,044	4,019	--	--	2,600

[a]Wastes are discharged through two outlets. This sample was taken from channel after the two flows combined. Wastes from pulp cookers not being discharged at this time. One per cent settleable solids by volume.

[b]Wastes from paper manufacturing process. Continuous discharge.

[c]Wastes from pulp cookers. Three vats discharge 20,000 liters waste each every four hours.

TABLE 13

RESULTS OF ANALYSES OF SAMPLE FROM CELANESA, STATION 148.4

Sample No.	Date	Hour	Flow, cfs	Temp., °C	pH	DO, mg/1	5 day 20°C BOD, mg/1	Residue on Evaporation, mg/1	Suspended Matter, mg/1	Volatile Matter, mg/1	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
1	7/1	1530	.8	35	8.8	--	32	1,129	730	306	--	--	140

tributaries that flow across the valley floor to the east of the Rio Cauca. No attempt was made to identify the numerous sources of waste that eventually find their way into the Rio Guachal. However, it is believed that the sanitary and industrial wastes of Palmira are eventually discharged to the Rio Cauca by means of the Rio Guachal. Sampling was done at the mouth of the river and the results are contained in Table 15.

A considerable pollutional load is imposed upon the Cauca at approximately Station 133.5. This is the location of the garbage dump for the city of Cali. Apparently a method of land fill had been initiated to dispose of such waste but is not presently being practiced. An unknown quantity of garbage and trash is pushed into the Rio Cauca daily by use of a dozer as illustrated in Figure 8. This material is high in organic content and undoubtedly imposes a considerable BOD load on the river. In addition, some of the material creates an unsightly condition as it floats down the river as shown in Figure 9. This floating material was observed as far downstream as Paso de la Torre, and at least one downstream industrial user reported that this material periodically clogs the submerged inlet of a pumping station and interrupts the normal plant operation.

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tributaries that flow across the valley floor [illegible]

of the Rio Chama. No attempt was made to identify the numerous sources of waste that eventually find their way into the Rio Guachal. However, [illegible] cemetery and industrial wastes of [illegible] discharged to the Rio Chama by means of [illegible] Sampling was done at the confluence [illegible] are contained in Table IV.

A considerable population [illegible] [illegible] of the pueblo [illegible] method of [illegible] has been [illegible] waste [illegible] quanti[illegible] daily [illegible] materi[illegible]

TABLE 14

RESULTS OF ANALYSES OF SAMPLES FROM RIO YUMBO, STATION 153.5

Sample No.	Date	Hour	Flow, cfs	Temp., °C	pH	DO, mg/1	5 day 20°C BOD, mg/1	Residue on Evaporation, mg/1	Suspended Matter, mg/1	Volatile Matter, mg/1	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
1	7/2	1005	10.8	22	>7.6	2.7	17	435	85	81	28	--	991
2	7/6	1030	10.8	22	>7.6	2.9	7.5	381	108	145	--	--	434
3	7/10	1410	10.8	24	>7.6	1.2	--	581	21	117	30	--	--

TABLE 15

RESULTS OF ANALYSES OF SAMPLES FROM RIO GUACHAL, STATION 155.0

Sample No.	Date	Hour	Flow, cfs	Temp., °C	pH	DO, mg/1	5 day 20°C BOD, mg/1	Residue on Evaporation, mg/1	Suspended Matter, mg/1	Volatile Matter, mg/1	Turbidity, Units	Coliform Count, MPN	lbs. 5 day BOD per day
1	6/26	1605	306	22	7.6	4.9	2.0	852	--	174	60	--	3,300
2	6/28	1245	306	22	7.6	4.3	3.8	348	159	41	42	--	6,270
3	7/1	1315	306	24	7.6	2.7	1.9	566	287	65	--	--	3,140
4	7/4	1100	306	22	7.6	5.5	4.4	377	40	44	--	--	7,270
5	7/5	1030	306	22	7.6	5.3	4.2	288	134	33	--	46,000	6,940

Figure 8.--Trash and Garbage Being Pushed Into Rio Cauca

Figure 9.--Trash and Garbage Floating Downstream of Dump.

Conclusions

The purpose of this part of the survey of the Rio Cauca was to locate and identify sources and quantities of waste entering that portion of the river under study. It is believed that all sources of water-borne wastes contributing a significant pollutional load to the Rio Cauca have been located and a sampling program initiated at these sites. Minor sources such as irrigation flow and streams or ditches with negligible or intermittent flow were not considered in the survey.

The original survey plan envisioned a more intensive sampling program than was carried out. The university students that were to assist in the taking of samples and performing of laboratory analyses were not available until late in the period allotted for the initial survey. As a result of this reduced number of personnel fewer samples than anticipated were collected and analyzed for some of the waste sources. However, a sampling program has been scheduled that will provide for the continued collection of data at numerous sites until the end of August. The results from this continued program will provide sufficient data to even out variations resulting from the collection of grab samples and thus provide more complete data. The results of this continued program combined with the results of the present study will provide the basic water

quality data desired for the evaluation and surveillance of waste loads entering the Rio Cauca.

The degree of pollution in the Rio Cauca at the present time and the determination of the additional wastes, if any, that can be discharged to the river is beyond the scope of this study. This phase is presently being investigated as part of the overall ICMRT project and specific conclusions and recommendations cannot be made until such an investigation is completed. However, the analyses of the samples of water-borne wastes entering the Rio Cauca indicates that pollution from heat, pH, and turbidity is probably negligible when the degree of dilution of these wastes by the river flow is considered. Likewise, although the thermo-electric plant, the two paper mills, and the city of Cali contribute a substantial solids load to the river, the natural solids load from the considerable erosion of the river banks and the load imposed by the tributary flow, particularly during the rainy seasons, tends to minimize the importance of pollution by solids. Pollution by organic material, on the other hand, is considerable and presents a problem that is becoming serious in nature. Preliminary river sampling indicates that the DO level in the vicinity of Paso de la Torre drops to below four milligrams per liter. This sampling was conducted during a period when the flow in the Rio Cauca was higher than

quality data desired for the evaluation and surveillance of waste loads entering the Rio Cauca.

The degree of pollution in the Rio Cauca at the present time and the determination of the additional wastes, if any, that can be discharged to the river is beyond the scope of this study. This phase is presently being investigated as part of the overall ICWPI project and specific conclusions and recommendations cannot be made until such an investigation is completed. However, the analysis of the samples of water-borne wastes entering the Rio Cauca indicates that pollution from Cali, as [illegible] probably significant [illegible] the degree of pollution of these wastes in the river [illegible] is considerable. [illegible] the thermo-electric [illegible] the [illegible] city of Cali [illegible] [illegible]

[illegible]

[illegible]

normal for this time of year and the DO value will certainly become lower as the river flow decreases during the summer. Fish kills have occurred in the past in the vicinity of Paso de la Torre and little fishing activity was observed below Puerto Isaacs.

The waste survey conducted disclosed that significant water-borne organic pollution is discharged into the Rio Cauca in fifteen different locations between Paso de la Bolsa and Paso de la Torre. A summary of the average daily oxygen demand imposed upon the river is shown in Table 16. These results indicate that the BOD loads from these sources vary from as low as 27 pounds to as high as 54,200 pounds of 5-day 20°C BOD. The total load of 197,444 pounds indicates a considerable amount of organic pollution is being introduced into the Rio Cauca daily.

It is apparent from the results of the sampling accomplished that there are three sources contributing the greater part of the organic pollution to the Rio Cauca. These sources, the city of Cali and the two pulp and paper factories, contribute 75 per cent of the average daily load to the river as indicated in Table 16.

The pollutional load from two of these sources will undoubtedly increase considerably in the near future. A pulp mill which will produce pulp by a modified Kraft process is being constructed adjacent to the paper mill at

normal for this time of year and the DO values will cer-
tainly become lower as the river flow decreases during
summer. Fish kills have occurred in the past in the
vicinity of Paso de la Torre and little [illegible]
was observed below Fuerte [illegible]

The whole survey conducted [illegible]
water-borne organic pollution [illegible]
Chace in fifteen different locations [illegible]
Sulaa and Paso de la Torre. A sample [illegible]
oxygen demand [illegible]
These results indicate that the BOD [illegible]
vary from [illegible]
of [illegible]
cells [illegible]
Intro[illegible]

[illegible]

TABLE 16

SUMMARY OF DAILY 5 DAY BOD LOADINGS

Source	Station	Average 5 Day 20°C BOD in Lbs. Per Day	Percent of Total
Rio Claro	73.7	567	0.3
Rio Palo	93.4	4,082	2.1
Rio Jamundí	103.2	2,071	1.0
Zanja Granadillo	113.0	27	--
Navarro	120.9	7,730	3.9
Cauquita	129.9	31,420[a]	15.9
Cali	136.5	18,890[a]	9.6
Acopi	136.5	35,660	18.1
Propal	140.7	54,200	27.4
Cementos	148.1	136	0.1
Eternit	148.2	27	--
Carton Colombia	148.3	36,500	18.5
Celanesa	148.4	140	0.1
Rio Yumbo	153.5	610	0.3
Rio Guachal	155.0	5,384	2.7
Total		197,444	100.0

[a]The combined average daily load from Cali is 58,040 pounds of 5 day 20°C BOD or 29.4 per cent of the total.

Station 148.3 and is expected to be in operation before the end of the summer. The waste from the pulp produced will substantially increase the pollutional load imposed upon the Cauca.

Additionally, the city of Cali is presently constructing a number of interceptor sewers as part of an overall sewer improvement project being carried out by Empresas Municipales. A number of these interceptors are expected to be completed and in service within two years and it is anticipated that the overall project will be completed within ten years and will ultimately discharge all of the wastes from Cali into the Rio Cauca at one central location.

This improvement project will result in a greater quantity of waste being discharged into the Rio Cauca as the population of Cali will increase considerably in ten years if the present rate of growth continues, and the area served by the sewer system will be greatly enlarged as a result of the newer barrios being developed to house this growing population. Further, the wastes will arrive at the Rio Cauca in a much fresher condition than at the present. The existing sewer system is composed of conduits, open and closed ditches, and canals. The hydraulics of the system are quite poor and considerable sedimentation and decomposition occurs before the wastes arrive at the

Station 120.3 and is expected to be in operation by the end of the summer. The waste from the pole yard will substantially increase the pollutional load placed upon the Lasoa.

Additionally, the city of Cali is presently planning a number of interceptor sewers as part of an overall sewer improvement project being carried out by Emcali (Municipales). A number of these interceptors are expected to be completed and in service within a few years. It is anticipated that the sewer project will be completed within ten years [illegible] wastes from Cali [illegible] location.

This [illegible]

quality [illegible]

the [illegible]

points of discharge into the Rio Cauca. The new system has been designed[1] to eliminate these conditions and therefore the decomposition that is presently taking place in the sewer system will occur in the Rio Cauca and cause a substantial increase in the BOD in the river.

Additional industries will continue to locate in the vicinity of Cali as the economic growth of Colombia increases. These industries will undoubtedly continue the present practice of disposing of untreated wastes by discharging them into the river.

It is possible, therefore, to make some general recommendations regarding action necessary to maintain or improve the condition of the Rio Cauca. First, the practice of pushing garbage and trash from the Cali dump into the Rio Cauca should be stopped immediately. Such action can be accomplished at no cost and will considerably reduce the organic load and unsightly condition presently imposed upon the river.

Second, the city of Cali should implement a plan for the study, design, and construction of a sewage treatment plant. The organic load that will be introduced into the

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[1] Informe General sobre las Investigaciones, Estudios y Diseños para el Alcantarillado de Cali (General Report about the Investigations, Studies and Designs for the Sewer System of Cali), R. J. Tipton y Asociados de Colombia Ltda., Cali, September 1, 1956.

Cauca upon completion of the present sewer improvement project will be the largest single pollution source in the area under study. A treatment plant is a necessity if pollution control is to be implemented in the Cauca Valley.

Finally, the CVC should take steps to adopt and enforce pollution control measures. The present CVC authority includes the regulation and use of water for public and industrial consumption and for the protection of water against pollution. This authority should be exercised if further deterioration of the water quality of the Rio Cauca is to be prevented.

It is realized that the use of the Rio Cauca downstream of Yumbo is minimal at the present time. As a result, there are undoubtedly many interested parties that maintain that a pollution problem does not exist inasmuch as the present condition of the river does not interfere with downstream use. It is the opinion of this investigator, however, that downstream use of the river will increase as the economic growth and development of the Cauca Valley continues.

In order to protect this natural resource so important to the continued growth of the valley, it is believed that pollution control measures should be implemented before the pollution problem becomes more serious than it is at the present. The pollution measures adopted should take into consideration the future river flow regulation, hydro-

Creek upon completion of the present sewer [illegible] project will be the largest single [illegible] area under study. A treatment [illegible] pollution control is to be [illegible]

Finally, the [illegible] pollution control [illegible] include [illegible] trial [illegible] pollution [illegible] deter[illegible] be practiced.

It [illegible] of [illegible] are [illegible] a [illegible] cond[illegible] use [illegible] do[illegible] gr[illegible]

[illegible]

electric, irrigation, and drainage projects presently planned by the CVC. In addition, the anticipated industrial growth of the area should play an important role in the drafting of these measures. The use of the river must of necessity include the purpose of carrying away wastes if the economic development of the valley is to continue. It is the matter of controlling the quantity and quality of waste discharged to the river that must be considered. Overly strict or unreasonable measures are to be avoided if industries are not to be discouraged from establishing in the area. The development of the Cauca Valley must continue, but it must continue in a manner that is in the best interest of all concerned.

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BIOGRAPHY

Jacques Edward Donaldson was born in Masury, Ohio, on January 29, 1929. He lived in this immediate area for the next 22 years during which time he received his primary education in the Brookfield Township School System. In 1951 he enrolled at Tri-State College, Angola, Indiana, and received the degree of Bachelor of Science in Civil Engineering from that institution in 1954.

Upon graduation from college he was employed in the Structural Research and Development Section of Chance Vought Aircraft Corporation in Dallas, Texas. In 1955 he entered the United States Navy and received his commission as an officer in the Civil Engineer Corps. During the next seven years he completed tours of duty with the District Public Works Officer, Philadelphia, Pennsylvania; as Assistant Public Works Officer, Naval Air Station, Brunswick, Georgia; Resident Officer in Charge of Construction and Project Manager with the Officer in Charge of Construction, BUDOCKS Contracts, Madrid, Spain; and Assistant Public Works Officer, Naval Air Station, Lakehurst, New Jersey. He was selected by the Navy in 1962 to attend Tulane University for a period of one year

as a candidate for the degree of Master of Science in Civil Engineering.

He was married to Dora Cleveland in 1950 and is the father of two children, Mark and Diane.